NAVY'S MODELING OBJECTIVES

- **The objective of groundwater modeling will be to help ascertain potential risk to water supply wells as a result of a potential range of releases from the Red Hill Bulk Fuel Storage Facility under a range of reasonable pumping conditions within the model domain.**

  The results of this modeling effort will then be used to:

  1. Inform decisions related to the Tank Upgrade Alternatives (TUA), and

  2. Inform decisions related to potential remediation options

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- **The intent of the GWFMWG is to support the Navy's objectives relative to developing timely and technically defensible flow and F&T models for Red Hill as follows:**

  - ➤ **Dialogue with Subject Mater Experts (SMEs) for consideration by the Navy on key elements of model development**

  - ➤ **Provide assistance in ensuring that all appropriate data are considered in development of the model**

  - ➤ **Provide assistance in collecting pertinent data**

  * The GWFMWG focus is on the deep technical issues related to technically defensible model development

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Spreadsheet Approach

- ➢ Format
- ➢ Issues/Responses Raised Prior to Second GWMWG Meeting
- ➢ Response to BWS Comments from Meeting #2
- ➢ Response to BWS Comments from Meeting #3
- ➢ Issues/Responses Going Forward

MODEL APPLICATIONS FOR MEETING NAVY'S OBJECTIVES

- **Evaluate flow field and capture zones of wells within the model domain**
  - Scenarios of different combinations of possible future pumping
    - Long-term analysis
    - Impact of seasonal changes
    - Impact of uncertainty in parameters or stresses
- **Evaluate fate and transport of contaminants**
  - Scenarios for different source considerations
    - Long-term analysis
    - Impact of seasonal changes
    - Impact of uncertainty in parameters or stresses
- **Help evaluate containment / remediation / monitoring strategies**
- **Not to predict future, but to evaluate impact of potential scenarios**
  - Modeling (achieves our goal) – constructing a model to answer a specific objective
  - Simulation (this is not our goal) – constructing a model to mimic as many aspects of a portion of the natural world as possible
  - Henk Haitjema, 1999 AGU Meeting
- **Final Modeling Report to be provided to EPA/DOH (and other stakeholders) on December 5, 2018**

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MODELING OBJECTIVES TIMELINE

Interim Objectives:

1 Construct model (i.e., geology/ hydrogeology); establish boundaries, input parameters (i.e., hydraulic conductivity, recharge) (Nov 20, 2017)

2 Calibrate interim flow model (Dec 17, 2017)

3 Run capture zone analysis under different pumping scenarios (Dec 31, 2017)

2017						2018												2019				
Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun

1   3   4   5   6   7   8

2

Final Objectives:

1 Discuss conceptual hydrogeologic framework (Jun–Oct 2017)

2 Define future pumping scenarios (Aug 2017–Apr 2018)

3 Present groundwater flow system CSM (Oct–Nov 2017)

4 Set up numerical flow model (Jan–Feb 2018)

5 Flow model calibration (Apr–May 2018)

6 Present initial flow modeling results (Aug–Sep 2018)

7 Prepare Groundwater Flow Model Report – AOC deliverable (Sep–Dec 2018)

8 Prepare CF&T Model Report – AOC deliverable (Mar–Jun 2019)

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- **Both flow and particle tracking models will be developed and run on an interim basis in order to:**
  - Support decisions related to the TUA in early 2018
  - Provide sensitivity analyses relative to further developing a technically defensible model
- **Certain natural attenuation analyses will be conducted in parallel to this effort to support the interim model.**
- **The final report on the interim modeling effort will be provided by the Navy to EPA/DOH (and other stakeholders) on January 31, 2018**
  - Updates on the interim modeling will be provided during GWFMWG meetings prior to issuing the final report.

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INTERIM MODEL DEVELOPMENT EXPECTATIONS

- **Develop Numerical Model**
  - ➢ Translate CSM and steady-state boundary conditions to numerical model
  - ➢ Translate steady-state calibration targets to numerical model
- **Preliminary Steady-State Calibration**
  - ➢ Run groundwater flow model with initial parameterization to evaluate and tune solver parameters
  - ➢ Run parameter and boundary sensitivity scenarios to evaluate groundwater flow model behavior for calibration
  - ➢ Calibrate groundwater flow model by interactive expert methodology and automatic adjustments with PEST
  - ➢ Run particle tracking simulations to evaluate flow directions and prepare for interim model applications

- **Capture zones using reverse particle tracking from extraction wells**
  - Pumping at current annual average conditions
  - Pumping at select anticipated combination scenarios
- **Projected migration assessments using forward particle tracking**
  - Tracking originating from selected sites
  - Pumping at current annual average conditions and select anticipated combination scenarios
- **Parameter and predictive sensitivity assessments for bounding the impact of select parameters and boundary stresses for select capture zone and projected migration assessments**

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POST-INTERIM MODEL EXPECTATIONS

- Refine steady-state calibration as required
- Transport model development and verification against MT3D
- Evaluate transport in steady-state flow field
  - Impact of pumping at current annual average conditions
  - Impact of pumping at select anticipated combination scenarios
  - Impact of select source strengths and locations
  - Evaluate containment / remedial alternative designs
  - Bounding sensitivity of impact to flow, transport and decay parameters for select scenarios
  - Sensitivity to source strength and duration
  - Evaluate need for and practicality of formal statistical uncertainty evaluations
- Transient groundwater flow model development and calibration
- Evaluate particle tracking and transport over transient annual flow cycle for various scenarios / remedial designs / predictive sensitivities as required

Groundwater MODFLOW Model Comparison Table

Pros/Cons	2005	NWT	USG
Supported by GMS (can readily convert between numerical models)	X	X	X
Capable of handling site complexities	X	X	X
SWI2 Compatibility	*	*	
Interfaces w/ MT3D (linear decay)	X	X	**
Simulation of multi-layer wells (MNW/CLN Packages)	X	X	X
Alleviates drying/wetting issues		X	X
Flexible gridding to provide target resolution			X
Interfaces with RT3D (complicated reactions)	***	***	
Structured rectangular grid	X	X	
Can have drying/wetting issues	X		
Wells represented as sinks from a groundwater cell	X		

* SWI2 incompatible with MT3D and RT3D

** Solute transport routine with linear decay is built-in to MODFLOW-USG (Beta)

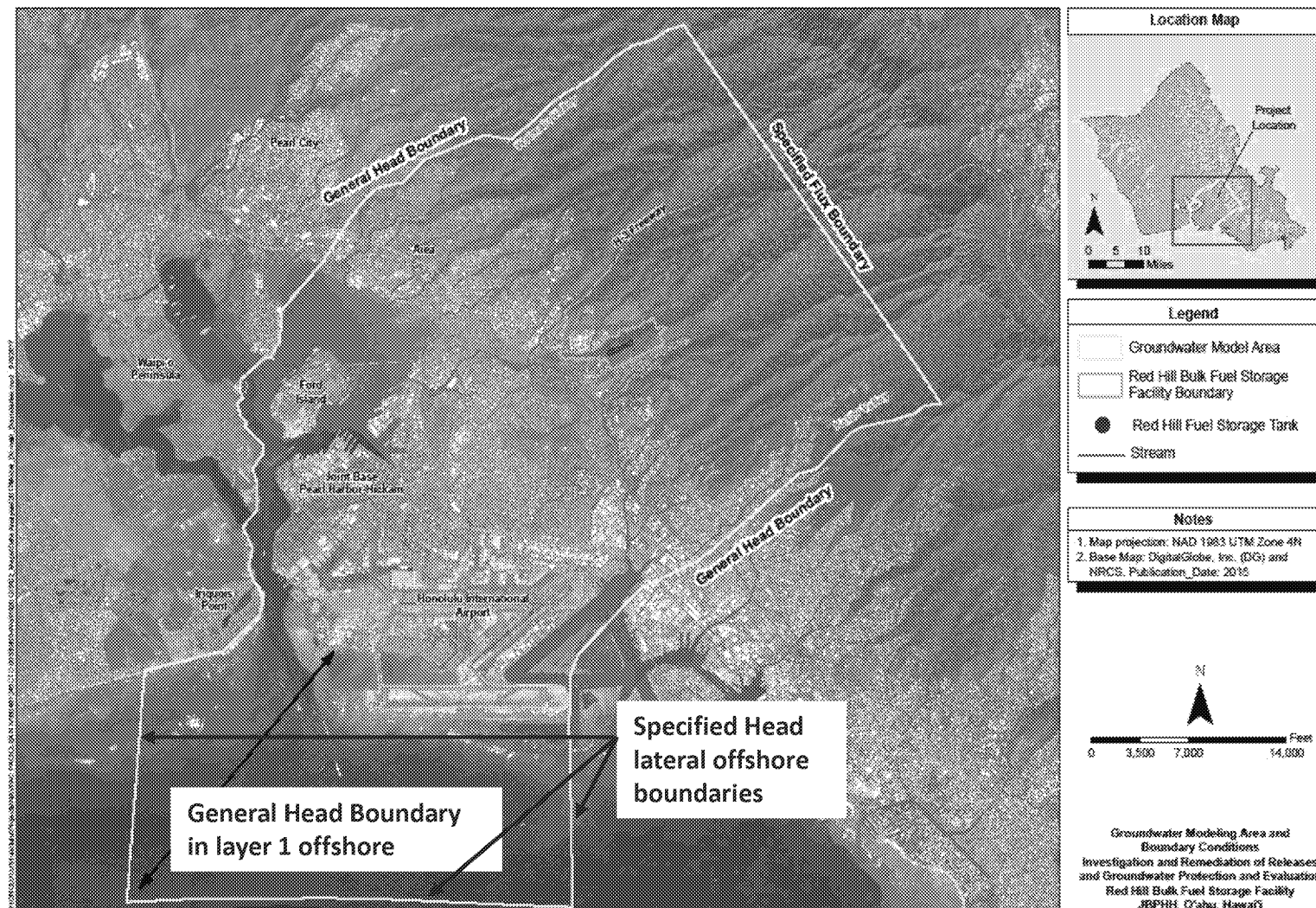*** RT3D is not anticipated for this modeling effort

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- **Code should be capable of simulating project objectives and handling site-related complexities**
  - ➢ MF2K5, NWT, and USG are capable
- **Code should be robust to handle extreme stresses that may be tested in predictive simulations**
  - ➢ NWT and USG provide advanced solution schemes
  - ➢ Runs focus on hydrogeology and calibration rather than evaluating/correcting for convergence or dry cells/wells
- **Code should be efficient**
  - ➢ Unstructured grids of USG can increase simulation speed by an order of magnitude
  - ➢ More simulations translates to a more refined calibration within the same timeframe
- **Conceptual model created in GMS**
  - ➢ Can switch between simulators as needed
  - ➢ Will validate transport routines in MODFLOW-USG against MODFLOW-NWT / MT3DMS

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UPDATE ON USGS SYNOPTIC WATER LEVEL STUDY

- **Delwyn Oki**

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MODEL DOMAIN AND BOUNDARIES

Groundwater Modeling Area and Boundary Conditions
Investigation and Remediation of Releases and Groundwater Protection and Evaluation Red Hill Bulk Fuel Storage Facility JBPHH, O'ahu, Hawai'i

- **Location: Offshore to a distance coincident with location where saltwater/freshwater interface (50% salinity) outcrops into the sea**
  - ➢ Simulating only freshwater portion of groundwater
- **Bottom Boundary: No flow along saltwater/freshwater interface**
  - ➢ Allows appropriate freshwater transmissivity to be simulated
  - ➢ Keep the model as simple as possible and still answer the pertinent questions

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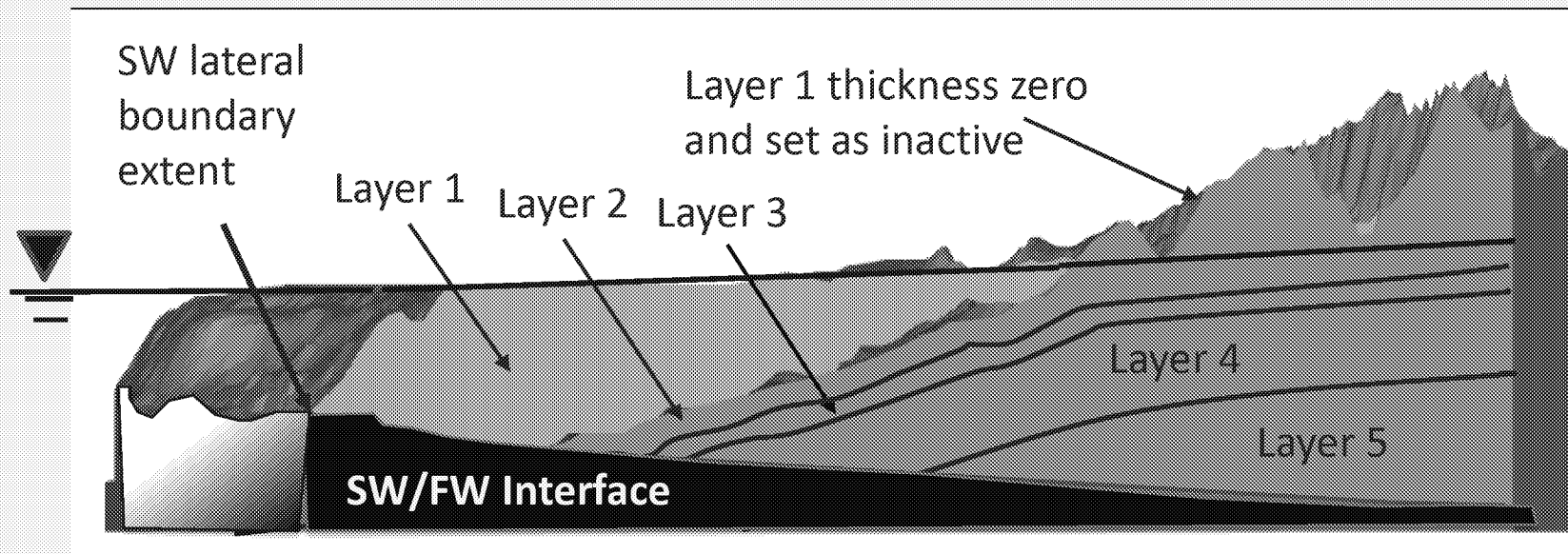
DEEP BOUNDARY – ALONG SW/FW INTERFACE

- **Methodology used for groundwater modeling in Hawai'i**
  - Glenn C. R., R. B. Whittier, M. L. Dailer, H. Dulaiova, A. I. El-Kadi, J. Fackrell, J. L. Kelly, C. A. Waters, J. Sevadjian. 2013. *Lahaina Groundwater Tracer Study, Lahaina, Maui, Hawai'i, Final Report.* For State of Hawaii Department of Health, US Environmental Protection Agency, and U. S. Army Engineer Research and Development Center.
  - Ghazal, K. A., O. T. Leta, A.I. El-Kadi, H. Dulai. 2017. *"Modeling fresh submarine groundwater discharge across the Heeia coastal shoreline in Hawaii."* MODFLOW and More 2017 Conference Proceedings, pages 225 to 227. Motz, L.H., 2004. Representing the Saltwater-Freshwater Interface in Regional Groundwater Flow Models, 18 SWIM. Cartagena 2004, Spain. (Ed. Araguás, Custodio and Manzano). IGME
  - Whittier, R. B., K. Rotzoll, S. Dhal, A. I. El-Kadi, C. Ray, D. Chang. 2010. *"Groundwater source assessment program for the state of Hawaii, USA: methodology and example application."* Hydrogeology Journal (18): 711-723.
  - Whittier, R.B., P. Eyre, J. Fackrell, and D. Thomas. 2015. *Merging Isotopic Chemistry with Numerical Modeling to Investigate Groundwater Flow Paths,* Presentation to the Commission on Water Resource Management, Kona, Hawai'i – May 20, 2015. files.hawaii.gov/dlnr/cwrm/presentations/pp20150520-Whittier.pdf.

- **Methodology used for groundwater modeling in saline systems**
  - Brakefield, L., J.D. Hughes, C.D. Langevin, and K. Chartier. 2013. *Estimation of Capture Zones and Drawdown at the Northwest and West Well Fields, Miami-Dade County Florida, using an Unconstrained Monte Carlo Analysis: Recent (2004) and Proposed Conditions.* USGS Open-File Report 2013–1086
  - Paschke, S.S. ed. 2007. *Hydrogeologic Settings and Ground-Water Flow Simulations for Regional Studies of the Transport of Anthropogenic and Natural Contaminants to Public-Supply Wells—Studies Begun in 2001,* National Water-Quality Assessment Program, USGS Professional Paper 1737–A, 244p.

DECISION TO PRECLUDE SWI2 FROM NAVY MODEL

- **Saltwater interface movement is not a simulation objective**
  - Simulation objectives are at shallower depths (within 20-100 feet of water table)
  - Saltwater interface is deep (at 1,000 feet depth beneath the Red Hill Area)
  - Vertical hydraulic conductivity is low
  - Impact of shallow pumping on deep interface is relatively small (Oki, 2005)
- **Use of the SWI2 Package hinders simulation objectives**
  - Cannot do particle tracking directly with results of model – need to adjust fluxes and not have particles crossing zeta surfaces
  - Cannot run transport (MT3D) with results of model – need flux adjustments, and conversion of equivalent freshwater head but also possible other hidden issues in transport related to zeta surfaces
- **Impedes timely development of a tool to answer relevant questions**
  - Efficiency – preliminary tests indicate 20 minutes (w SWI2) vs 2 minutes (no SWI2)
  - Robustness – convergence may be hindered in calibration and in future pumping cases
  - Distracts from focus of simulation in shallow zone and onshore

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DECISION TO PRECLUDE SWI2 FROM NAVY MODEL

- **Tracking the saltwater interface location and movement does not make the model more accurate**
  - ➢ **Vertical movement of interface is small compared to saturated thickness**
    - – Oki, (2005) shows 2% salinity isochlor moving by up to 10 to 20 feet due to pumping 5.6 MGD from Halawa Shaft
    - – 50% isochlor movement will be even less without diffusion / dispersion (SWI2 approximation)
  - ➢ **Impact of interface movement by 10-20 ft is negligible on transmissivity for freshwater for a depth of over 1000 feet.**
    - – Oki, (2005) neglects similar impact on transmissivity by neglecting aquifer above water table
  - ➢ **This is not novel for when saltwater tracking is not the objective**
    - – Resource evaluation models of the island have been run with MODFLOW (without SWI2)
    - – Other coastal aquifer analyses have been performed with MODFLOW using various approximations

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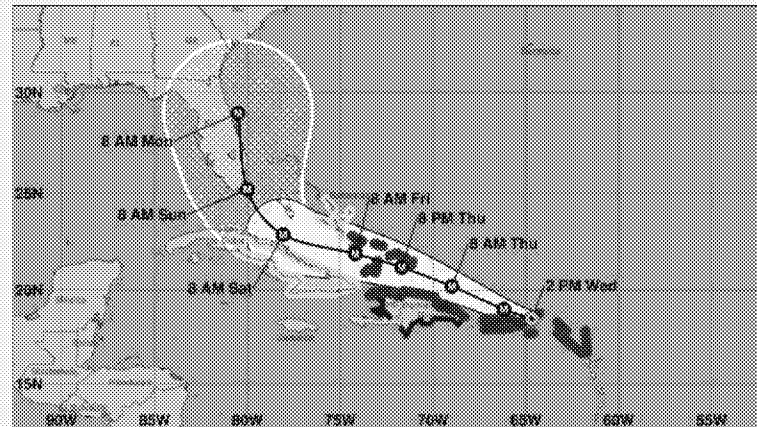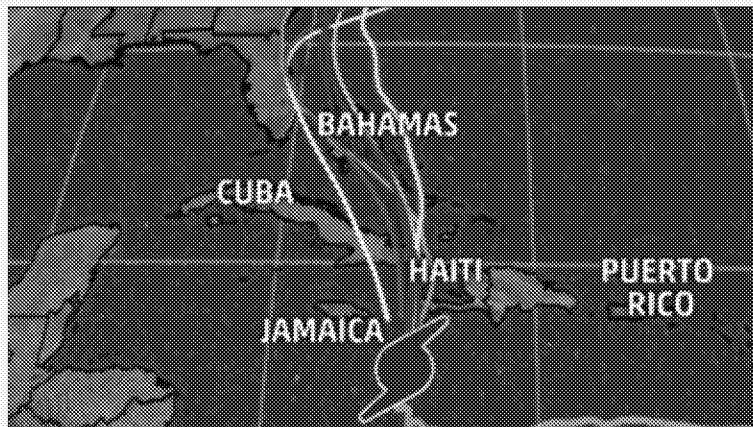# CONSIDERATIONS FOR MODEL CALIBRATION

- **Groundwater flow model calibration will consider available data, fluctuations in available data, and long-term changes in available data to capture impacts that need to be analyzed**
  - Steady-state flow model of current conditions from the current synoptic water level survey and other available data
  - Smaller temporal scale considerations such as seasonal / monthly variations in pumping or other boundary conditions
- **Groundwater flow model use**
  - Use current flow-field for estimating current impacts
  - Evaluate impact of various scenarios of pumping on water levels and flow field
  - Use smaller temporal scale flow-fields for evaluating flow and transport impacts of decisions / actions that may occur at monthly or seasonal scales

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TARGETS FOR
MODEL CALIBRATION

- **Synoptic water level study**

- **Available historic water level data projected to current conditions**

- **Available spring flow estimates for current conditions**

- **Flow gradients and directions interpreted from nearby wells**

- **Targets for calibration will be weighted to provide greater focus on recent and more accurate information**

- **Steady-state calibration to: Latest available annual average recharge, pumping and WLE conditions (2016-2017)**

- **Transient calibration to: Latest annual cycle (2016-2017) for recharge, pumping and WLE conditions**

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FORMAL CONSTRAINED UNCERTAINTY EVALUATION AND MODEL COMPLEXITY CONSIDERATIONS

- Stepwise modeling – flexibility to find adequate complexity (Henk Haitjema, 2011)
  - Numerical behavior
    - Speed
    - Robustness
  - Calibration behavior
    - Model calibrates well with minimal parameterization
    - Density of observations and calibration targets
    - Observation errors – Seasonal; barometric
- There are other methods of evaluating uncertainty
  - Evaluate the impact of ranges of parameters on predictions of interest
  - Display bounding results – such as the spaghetti plots or path cones depicted for hurricanes (recently seen on TV for Hurricane Irma)
- We will consider highly parameterized (pilot points) calibration and formal constrained uncertainty evaluations only if needed

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FORMAL CONSTRAINED UNCERTAINTY EVALUATION AND MODEL COMPLEXITY CONSIDERATIONS

- **Simplicity versus complexity debate is not resolved**
  - ➢ **Clifford Voss Birdsall-Dreiss Distinguished Lecture (2015) on "Informing Management of the World's Largest Groundwater Systems with Simply-Structured Model Analysis"**
  - ➢ **A simple answer can convey a large part of a complex answer (Henk Haitjema, 1998)**
  - ➢ **Voss, 2011. Groundwater modeling fantasies – part 1, adrift in the details, Hydrogeology Journal, 19: 1281 – 1254**
  - ➢ **Voss, 2011. Groundwater modeling fantasies – part 2, down to earth, Hydrogeology Journal, 19: 1455 – 1458**

    "In the view of this writer, the best way to go forward with practical management is to rise above groundwater models as final products, and instead, empower hydrologists to provide advice by using groundwater models in simple ways that are intended to elucidate understanding. Pursuit of complexity in groundwater models intended for practical management is a diversion from the real work at hand."

  - ➢ **Voss, 1998. Groundwater Modeling – Simply Powerful, Hydrogeology Journal 6 (4).**

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MODELING ACTIVITIES UPDATE

- **Developing Zone Budgets from other models**
  - ➢ **SWAP (2004)**
  - ➢ **Local model (Rotzoll, El-Kadi 2007)**
  - ➢ **SWAP (2007) when model files are available**
  - ➢ **Oki (2005)**

- **Developing flow estimates from NE boundary**
  - ➢ **Zone budgets from various models**
  - ➢ **Water balance of recharge upstream of NE boundary up to topographic divide (~ also hydrogeologic divide)**
    - – **Recharge estimates in SWAP model**
    - – **Recharge estimates from Oki (2005)**
    - – **Annual average precipitation / runoff / ET estimates**

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- **Developing model domain**
  - Top elevations from topography and bathymetry
  - Bottom elevation from interpreted saltwater/freshwater interface
  - SW lateral boundary at location of intersection of interface and model top elevation
- **Developing model layering and grid**
  - As discussed earlier
- **Other**
  - CSM Progress
  - Natural Attenuation Progress

CURRENT SUMMARY OF WELL DATA SHARING

BWS Data Request Status Summary		
Aquifer System	Moanalua	Waimalu
# Wells Information Requested For From BWS	10	42
BWS Response (8/22-9/15/2017)		
Wells with Driller's Log and/or Well Construction Records	3	39
Wells with GW Elevation Records (Drillers/Subsequent)	2/0	11/5
Wells with No BWS Records	1	1
Wells with Complete Data Records [a]	1	13
Wells with Complete Data Records, Minus Pumping Data	1	14
Wells with Pending Data [b]	6	37
Data Sources		
Wells BWS has data for that other entities do not	5	37
Wells other entities have data for that BWS does not	10	24
Wells that no entities have information for	9	25

[a] Complete' indicates the data provided by BWS included geologic and/or driller's log, well construction information, GW elevation records, and pumping

[b] 'Details of 'Pending Data' and 'Data Sources' are provided on the accompanying handout

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SUMMARY OF KEY ACTION ITEMS